trustworthiness there can not be the slightest doubt," is of great interest. He purports to have heard the sound three times in all and says that he is sure it could not reasonably be attributed to other causes.

The following contribution from Pilot O. J. Dahle (pilot on the *Haakon Adelsten*) dated March 30, 1910, was furnished me through the courtesy of Prof. Störmer:

Eight or nine years ago I witnessed from the steamship *Erling Jarl* an extraordinarily interesting aurora. While our ship was crossing Vaags Bay, a little north of Harstad, a brilliant aurora in rapid motion was seen so low down in the air that it barely cleared the tops of the masts. It flamed forth in all the colors of the rainbow and was followed by a peculiar sound, precisely such a sound as would be produced by rubbing together a well-dried skin in the hands. It was neither imagination nor the mistaking of any sound on board, but undoubtedly the result of the movement of the aurora. I have noticed also on other occasions that auroras in rapid motion hanging low in the atmosphere have emitted sounds similar to those mentioned above.

In the above-named display it seemed that the auroral rays had a horizontal position and appeared as separate layers, one above the other. But the probability is that it was a vertical ray which, by reason of its nearness and its position directly over the ship, appeared to to us to be horizontal and that the higher layers were the movements of the same ray seen through this identical ray from below.

The Finnish physicist, Lemström, has written a work entitled "The Polar Lights." Here also are several accounts, one by a miner from Göteborg who was in Lapland in 1842. He describes an aurora observed at night in midwinter in a temperature of – 45° C. A band of rays streamed up from the plateau between him and adjacent peaks and "a rushing sound could at the same time be plainly heard."

The well-known French balloonist, Rollier, who with an attendant ascended from Paris in 1870 during the siege and came down in Lifjeld , Telemarken, reports that he observed polar light rays through the light fog and, "presently a peculiar rushing sound was heard. A short time after, strong, almost suffocating fumes of sulphur were encountered."

Lemström himself, according to his own report, has never heard the auroral sound, but he specifically states that he is convinced of its existence, and this assertion is repeated several times. He speaks of the Laplanders' firm belief in the sound in the following language:

They say that a rumbling sound can often be heard and since it has frequently been observed by skilled observers, their belief that it actually exists in connection with strong, energetic auroras at low temperatures is absolute.

In a work by Prof. Hermann Fritz of Zurich, in 1881, concerning the polar lights, there is also collected from all sources a great number of accounts of the auroral sound. Upon examining these we come across many well-known men, even eminent scientists, who believe in the existence of this sound, for instance, Prof. Hansteen. We find also in this book various old Norwegian reports.

One would think since so many well-known and highly esteemed men have given such indisputable evidence of having heard the sound that all doubt would gradually be dispelled. But this is so far from being true that, on the contrary, many scientific men, for instance, the famous explorers, Leopold von Buch and Alexander von Humboldt, assert unqualifiedly that it is nothing but imagination. Humboldt says the native population knows nothing of the auroral sound and that it is the transients who have brought the belief with them. But this is a singular misapprehension of the facts, for the belief is especially widespread among the natives. "The polar lights have grown more taciturn," says Humboldt, "since we have learned to observe them more closely," and that is quite possible, for there are probably numerous false reports of the auroral sound, especially those that report it as audible at the time the lights are most active and vivid, for it requires a certain time in which to traverse the distance to the observer.

On the other hand it is not always when the aurora drops down moderately near the earth that it can be heard. There are numerous accounts of the polar lights which, judging from the observers' descriptions, have been very near the surface of the earth and which according to these descriptions have not been accompanied by any sound.

In a work on the height of the aurora by Cleveland Abbe in Terrestrial Magnetism, 1898, are cited a great number of reports of such displays which have been seen against the mountains and hence very near the earth, as for instance, that of the well-known polar explorer, Parry. Sir William Hooker saw the same phenomenon at Ben Nevis, Scotland. General Sabine observed an aurora that was so low that it lay like a fog over the ground, through which he walked. Galle, the famous astronomer, saw a cloud growth following an aurora and also a display very similar to that which I observed in Finland, and I cite Galle's observations here because the account of such a man surely ought to be given great weight. It seems therefore incontrovertible that the aurora, under certain conditions, may reach down into the atmosphere at least to the altitude of the cirrus level, approximately 6,000 meters.

EDITOR'S NOTE.—In a letter from the author, dated Christiania, November 27, 1913, he adds:

* * * It will perhaps interest you to hear that the only Norwegian member of the Scott Antarctic Expedition, Mr. Trygve Gran, once heard a peculiar noise attending an Aurora Borealis [i. e., Aurora Australis] and Mr. Gran also told me that the party of Lieut. Campbell had repeatedly heard such a noise.

THE METEOROLOGICAL ASPECT OF THE SMOKE PROBLEM.[1]

By HERBERT H. KIMBALL.

THE ATMOSPHERE AND ITS CONTENTS.

Atmospheric gases.—The terrestrial atmosphere consists of a mixture of gases that may be divided into two quite distinct classes: (1) The elementary gases, such as nitrogen, hydrogen, oxygen, and the gases of the argon group; (2) the compound gases, such as vapor of water, ammonia, ozone, carbonic acid gas, etc.

The gases of the first group are practically fixed in amount with respect to one another at any given level (1), while those of the second group are constantly varying not only with respect to the atmospheric conditions, such as temperature, pressure, and humidity, but also with respect to place. This is especially true of gases generated in the processes of combustion, which may be almost unknown in thinly inhabited districts, but which have to be taken into account in the atmospheres of large cities (2).

The gases of the atmosphere hold in suspension considerable quantities of solid and liquid particles. The latter consist principally of condensed water vapor, forming fog and clouds, which may hold in solution substances of various kinds, including some acids, as has been shown by numerous analyses of rain water and snow. The solid particles may be divided into several

[1] Condensed, with additions and revision, from Smoke Investigation Bulletin No. 5, Mellon Institute of Industrial Research and School of Specific Industries, University of Pittsburgh, 1913.

classes, such as cosmical or meteoric dust, finely divided mineral matter or soil from the surface of the earth, pollen from plants, microscopic organisms such as bacteria and molds, and the soot and other residues of combustion.

Atmospheric dust.—Much of the dust consists of particles so fine that, as Barus (**3**) states, it may be considered "an integrant part of the atmosphere." Meteoric dust is of this character, and Young (**4**) has estimated that the amount received by the entire atmosphere probably can not exceed 100 tons per day, which would produce a covering an inch thick on the surface of the earth only after the lapse of 1,000,000,000 years.

Humphreys (**5**) has suggested that certain observed sudden changes in the positions of the neutral points of sky polarization a few minutes after sunset or before sunrise may be attributed to the existence of well-defined dust layers in the atmosphere. The first of these is the dense dust layer that is often observed from mountain tops to cover the valleys and plains below. It consists of comparatively coarse particles caught up by the turbulent surface wind, and is usually less than a kilometer in thickness. Above this, extending to a height of about 4 kilometers, is the second layer, throughout which some of the finer particles of the first layer have been distributed by means of diurnal convection currents, which are especially strong in summer. The third layer extends from the top of the second to the region of the upper inversion, or to a height of about 11 kilometers, and throughout it some of the finer dust particles of the lower layers are distributed by means of the convective action of cyclones. Above the region of the upper inversion, which is also above the upper limit of convection, what little dust is present must be mostly of meteoric origin, except that volcanic dust is sometimes thrown into these high levels. This was shown to be the case after the great Krakatoa eruption of 1883, by the brilliant twilight phenomena of the two succeeding years.

The surface dust layer.—Nearly all human activities are carried on in the lowest dust layer, which is therefore of primary importance. Its density depends upon the relation between the rate of supply and the rapidity with which the particles can be carried away, or distributed throughout the atmosphere. The least dust is found in thinly inhabited regions covered with dense vegetation. In arid regions the surface wind takes up great quantities of dust, which is distributed with considerable rapidity by means of active convection currents. It is in great cities, however, and especially where bituminous coal is burned, that the discharge of soot from numerous chimneys produces the densest dust or smoke layer.

Quantity of soot in the air of cities.—Measurements made in Leeds, England, indicate that factories and domestic chimneys annually introduce into the atmosphere of that city 35,000 tons of soot, and into the atmosphere of the United Kingdom 2,420,000 tons. The measurements also show that there is 200 pounds of soot suspended in the air over each square mile of Leeds; that about 11 per cent of this falls in the immediate region where it is generated, and that the remainder is carried to considerable distances before it is deposited (**6**).

An analysis of air collected just outside a second-story window of the University of Pittsburgh, in the residence section of Pittsburgh, Pa., gave for the month of May, 1912, an average of 0.0079 grams of soot per 1,000 cubic feet of air, and for January, 1913, 0.0149 grams. These amounts are equivalent to 200 pounds of soot over each square mile of area in a layer of air about 410 feet and 220 feet thick, respectively.

On foggy days about twice as much soot was found in the air of Pittsburgh as on clear days.

Deposit of soot in city and country districts.—By means of soot gages, and from the analysis of rainfall and snowfall, fairly accurate determinations have been made of the rate of deposit of soot at different points on the British Isles and elsewhere. The following are some of the results:

Rate of deposit of soot in tons per annum per square mile.

British Isles:	Tons.
Industrial center of Leeds (**7**)	539
Suburban residence section of Leeds (**7**)	26
Center of London (**8**)	426
Sutton, Surrey, just outside the metropolitan area (**8**)	58
Glasgow (**9**)	820
Bo'ness (**9**)	72

If the rate of deposit is nearly proportional to the density of the dust layer, as seems probable, it appears that the dust or smoke cloud over the central sections of Leeds, London, and Glasgow, must be from ten to twenty times as dense as in the nearby suburbs.

Measurements of the monthly rate of soot deposit were made at 12 different points in Pittsburgh, Pa., during the year ending with March, 1913. At the point of maximum deposit the annual rate was 1,950 tons per square mile; at the point of minimum deposit it was 595 tons per square mile, while the mean annual rate for all 12 points was 1,031 tons per square mile.

Limit of visibility.—Aitken (**10**) found a great variation with wind direction in the limit of visibility in miles of the air at Falkirk, which is so situated that west to north winds come from regions having less than 50 inhabitants per square mile, while winds from all other directions come from regions having a population averaging from 100 to 1,200 per square mile. Table 1 summarizes his results.

TABLE 1.—*Mean limit of visibility in miles of air at Falkirk, for winds from different directions, and with different depressions of the wet-bulb thermometer.*

Direction of wind.	Depression of wet-bulb thermometer (degrees F.).						
	2°	3°	4°	5°	6°	7°	8°
West to north	50	100	132	132	198	193	191
All other directions	8	11	14	18.5	16.4	19	26

Aitken (**11**) has also shown that the product of the number of particles per unit of space by the limit of visibility is a constant C for equal depressions of the wet-bulb thermometer. Some of his results follow in Table 2.

TABLE 2.—*Value of C, the product of the limit of visibility in miles by the number of particles per cubic centimeter.*

Depression of the wet-bulb thermometer.	*C.*
2°–4° F.	77,525
4°–7° F.	105,923
7°–10° F.	140,628

From this table it appears that with a depression of the wet-bulb thermometer of about 5° F., 1,000 particles per cubic centimeter would produce complete obscuration of large objects like mountains at a distance of 100 miles, while 100,000 would produce complete obscuration at a distance of 1 mile, and 1,000,000 at a distance of one-tenth mile. Tables 1 and 2 are in accord with numerous observations, which indicate that the number of particles per cubic centimeter in large cities may exceed 300,000, even in fine weather, as compared with only a few hundred in the country (**12**). In London in winter the average limit of visibility in the clear part of the day does not exceed one-half mile (**13**), a limit of visibility which corresponds to 200,000 particles per cubic centimeter. In Pittsburgh, Pa., the limit at 7:45 a. m. averages 1.1 miles and at 12:30 p. m., 1.7 miles. This is less than one-tenth the limit at Mount Weather, Va., which has a climate similar to that of Pittsburgh, except that it is free from local smoke.

These figures, however, fail to indicate the relation between the dust or smoke cloud in thinly inhabited districts and in the centers of large cities when for any reason the smoke over the latter instead of being carried away at a reasonably rapid rate, accumulates for a considerable time.

METEOROLOGICAL EFFECTS OF THE IMPURE AIR OF CITIES.

It is the purpose of this paper to set forth our present knowledge of the effect of the smoke and other impurities in the atmosphere of large cities upon the meteorological conditions. From the preceding paragraphs it is apparent that these effects depend not alone upon the size of the cities and the rate of discharge of impurities into their atmospheres, but also upon the rate at which the vitiated atmosphere is carried away. It follows that the meteorological effects vary with geographical position and with the season of the year; that cities in regions having high average wind velocities are affected less than cities located in regions of light wind; and that the effects are less in summer than in winter, because in summer convection is active and helps to lift the impure air to levels where the stronger air currents will more quickly carry it away. Generally speaking, a city in a valley suffers more than a city in an open plain; and a city in high latitudes suffers more in winter than a city in lower latitudes, on account of the poleward decrease in the heating effect of the sun at this season.

Effect of smoke upon condensation.—Aitken (**14**) and others have shown that any considerable condensation of atmospheric moisture takes place only when the saturation temperature has been nearly reached, and then only upon *free surfaces*, such as the surfaces of suspended dust particles. Once condensation has set in, however, it can continue upon the surfaces of the fog particles already formed. In fact, by a process which Aitken calls *differentiation* the smaller fog particles tend to coalesce with the larger particles, until the latter become too heavy to be supported by the atmosphere, and fall to the ground. In this way a fog may rain itself out (**15**).

The analysis of the air of cities shows considerable sulphur dioxide in the residue from burning coal (**16**), and its presence is believed to increase the probability of the formation and maintenance of fog in two ways (**17**): (1) In the presence of sunshine nuclei are formed which have such an affinity for water that condensation sets in at temperatures higher than the saturation temperature; (2) chemical affinity soon arrests the process of differentiation referred to above, so that the fog particles maintain a small size and may be supported in the atmosphere for a long period.

Since there are always sufficient nuclei present in the atmosphere for purposes of condensation, the smoke and other impurities in the atmosphere of cities can not have an appreciable effect upon the amount of precipitation.

City and country fogs.—The cooling of the atmosphere to its saturation temperature is usually brought about by the mixture of warm and cold moist air currents, or by nocturnal cooling either by means of radiation outward or by radiation and conduction to the cold ground. These processes are operative in the country as well as in the city, except that the carbon particles in smoke, which are good radiators of heat, will cool below the temperature of the air in which they are suspended, thereby hastening the condensation of moisture upon their surfaces and the formation of fog. Carpenter (**13**) has pointed out that the principal difference between city and country fogs is that the former become mixed with smoke to such an extent that their color is changed from white to brown, or even to black, and their density is so increased that they are almost opaque to sunlight. They attain their greatest density when the surface wind is either very light or else has a direction opposite to that of the wind a short distance above, so that the smoke instead of being blown away is brought back over the city. The accumulation of smoke in fog is also facilitated by reason of the absorption by the soot particles of moisture from the fog, thereby so increasing their weight that instead of rising to their accustomed heights they quickly settle to the lower atmospheric levels.

While there is abundant proof of the increased density of fog in cities as compared with country fogs, the evidence is not conclusive that fogs are more frequent in the city than in the country. However, Brodie (**18**) thought he was able to detect an increase in fog frequency at Brixton, a suburb of London, with increased density of population in that section, and Aitken (**19**) has shown that dense haze or fog frequently forms after sunrise in the impure air of Falkirk when there is no hazing or fogging in the pure air of the surrounding country. There is also some evidence that fog frequency in London has decreased and the hours of sunshine have increased since 1890, perhaps due to a mitigation of the smoke nuisance through improvements in methods of heating and lighting (**18**, **20**). It is generally believed that the same was true of Pittsburgh, Pa., between 1885 and 1895, when the use of natural gas for both manufacturing and domestic purposes was quite general; but this will be referred to again in a later section.

Effects of impure air of cities upon fog dissipation.—In the case of chemical union, as where sulphur dioxide unites with water vapor from the air to form sulphurous acid, or where it is first oxydized and then unites with the water vapor to form sulphuric acid, the evaporation of the fog particles is retarded. Smoke from bituminous coal also contains oily or tarry substances (hydrocarbons) which form a coating on the fog particles and retard evaporation.

Furthermore, the increased opacity of black city fogs as compared with white country fogs prevents the heat rays from the sun penetrating to any considerable depth into the former, so that in a great city like London the fog frequently persists throughout the day, while in the suburbs it is dissipated by the midday heat.

Duration of sunshine in cities.—It is principally because of this persistence of city fogs that the observed hours of sunshine in large cities are less than in the suburbs. Thus, Russell (**21**) has shown that a station in the heart of London enjoys but seven-tenths as much sunshine as Kew, which is just outside the city, while for the months November to February, when the vertical component of the solar rays is very small, it may have less than one-third as much. Cohen (**22**) has shown that the duration of sunshine at the center of Leeds is 17 per cent less than at Adel 4 miles distant; and Rubner (**23**) concludes that the duration in Berlin is less than it would be if the smoke cloud were not present.

Intensity of sunshine in cities.—Rubner (**23**) further calls attention to the fact that a comparison of the hours of sunshine in cities and their suburbs is not a fair criterion of the actual deficiency of daylight in cities. He cites the fact that while overcast skies are the rule in Berlin in winter, and smoke can not, therefore, greatly diminish the hours of sunshine, measurements with a Weber photometer have shown that on an exceptionally dark day, such as might be attributed to the accumulation of smoke over the city, the light was only one five-hundredth what it was on an ordinary overcast day, and only one three-thousandth to one four-thousandth what it would have been on a day with an entirely clear sky.

Also, Cohen (**22**) has found that the intensity of the light in the center of Leeds is only 40 per cent of its intensity at Adel, a much greater loss than was indicated by the comparison of duration of sunshine at these two places, which is given above.

In Table 3 are summarized observations made at Pittsburgh, Pa., between November, 1912, and May, 1913, inclusive. The observations have been arranged in two groups, the first including days on which the presence of fog or smoke was not recorded, and the second including days on which light or dense fog or smoke was recorded. It will be noted that although the hours of sunshine are practically the same in each group, on days included in the second group fog or smoke has apparently decreased the limit of visibility 20 per cent, and the decomposition of oxalic acid 25 per cent, below the averages for the clear days included in group one. Furthermore, on the smoky or foggy days of the second group, with an average limit of visibility of 0.9 mile the decomposition of oxalic acid was only 76 per cent of what it was under apparently similar atmospheric conditions, except that the limit of visibility was 1.5 miles. In other words, a decrease of 40 per cent in the limit of visibility was accompanied by a decrease of 24 per cent in the decomposition of oxalic acid. It is presumed that the decomposition of oxalic acid is proportional to the intensity of daylight.

A comparison between observations made in Pittsburgh and in Sewickley, a small suburban town about 12 miles northwest of Pittsburgh, shows that the oxalic acid decomposition under the smoke cloud of the city is only 60 per cent of what it is in the country.

In both cases the glass vial containing the acid has been exposed outside the window in a small box with the open side facing accurately east.

TABLE 3.—*Relation between sky conditions and the decomposition of oxalic acid when exposed to daylight, at Pittsburgh, Pa.*

Hours of sunshine.	Limit of visibility.	Oxalic acid decomposition.
GROUP 1.—DAYS WITHOUT SMOKE OR FOG.		
	Miles.	*Per cent.*
4.1	1.2	13.74
4.0	1.8	14.43
GROUP 2.—DAYS WITH SMOKE OR FOG.		
4.1	0.9	9.06
4.2	1.5	11.99

Quality of daylight in cities.—Pyrheliometric observations (**24**) made at different places indicate a very considerable decrease in the intensity of direct insolation after violent volcanic eruptions, due without doubt to the scattering of the solar rays in passing through the dust or smoke that has been thrown to great heights by the eruption. Spectrobolometric measurements made under the direction of the Astrophysical Observatory of the Smithsonian Institution (**25**) show that light of short wave lengths suffers a greater depletion than light of long wave lengths in passing through a clear atmosphere, and that the further depletion in passing through a hazy atmosphere is relatively greater for short wave lengths than for long wave lengths. Furthermore, bolometric measurements made on Mount Wilson (**26**) in 1905 and 1906 indicate that the ratio of blue to red in diffuse skylight is six times the ratio of blue to red in direct sunlight.

The above accurate instrumental measurements confirm what we are able to observe with the unaided eye, viz, that both the direct and the diffuse solar radiation which filters through the smoke cloud hanging over cities is relatively poor in the blue light, or light of short wave lengths.

Although bolometric measurements of solar spectrum energies at the bottom of a smoke cloud are not available, it is safe to say that when the sun is near the horizon the smoke cloud over great cities almost completely extinguishes the blue light rays.

Effect of the smoke cloud on city temperatures.—The presence of dust or smoke particles in the atmosphere, by decreasing its transmissibility for light and heat waves as has just been shown, affects atmosphere temperatures in three ways:

(1) There is an increased scattering of the incoming heat rays, which are also partly absorbed by the dust or smoke particles, thereby raising the temperature of the atmosphere in which the latter are suspended.

(2) The rays reaching the surface of the earth are much weaker than they would have been if they had not been scattered and absorbed. In fact, in the case of dense fog or smoke almost no heat penetrates to the surface of the earth, but the upper boundary of the fog or smoke cloud becomes in effect the absorbing surface. In such cases the temperature above the cloud becomes much higher than the temperature in the cloud. Carpenter (**27**) mentions an instance in London where the surface temperature was 44° F., while on the roof, nearly vertically above and 59 feet higher, the temperature was 51.5°, or 7.5° higher, although generally the temperature was found to decrease with altitude at the rate of 0.52° F. per 100 feet. On this particular occasion the surface temperature rose from 36.5° to 44° between 9 a. m. and 3 p. m., or a range of temperature of 7.5°, while on the roof above it rose from 35° to 51.5°, or a range of 16.5°. At Kew, on the same date, the range was from 32.5° to 54°, or 21.5° F.

(3) There is less radiation from the ground and outward from the lower part of the atmosphere and from particles suspended in it. This tends to give higher minimum temperatures in cities than in their suburbs. In fact, this principle is extensively employed in protecting small fruits and garden truck from injury by frosts. A smoke cover is formed, which acts as a blanket to prevent the loss of surface heat by radiation.

On the whole, then, the effect of a smoke cloud is to raise the minimum temperatures, decrease the diurnal range of temperature, and, in case of a very dense cloud, to lower the maximum temperatures. It is possible to conceive of a smoke cloud of such depth and density that the maximum temperatures will be raised.

Hammon and Duenckel (**28**) found that the minimum temperatures at Forest Park, a suburb of St. Louis, Mo., were sometimes 20° F. lower than at the Weather Bureau office in the heart of the city. The differences were greatest in September when the air at the Park was clear, while light winds allowed the smoke to accumulate over the city in a dense cloud of great thickness. The differences were least in the cloudiest months—December and March. The thermometers at the Weather Bureau office were 110 feet above ground, and at Forest Park 10 feet.

Smith (**29**) has found a similar, though less marked, difference between the temperatures recorded at the Weather Bureau office, Columbus, Ohio, and the Ohio State University, located about 3 miles north of the center of the city. At the Weather Bureau office the thermometers have been exposed in a shelter on the roofs of several different office buildings, and at present are 170 feet above the ground. At the University the shelter is 6 feet above the sod. His conclusions are based on a summary of the observations for the 29 years, 1883 to 1911, inclusive.

The conditions at Pittsburgh, Pa., are of especial interest. According to the statement of Mr. Henry Pennywitt, in charge of the Weather Bureau office at Pittsburgh,—

> Previous to 1885, when soft coal was almost exclusively used for fuel for both domestic and manufacturing purposes, the air was ordinarily filled with smoke and soot, and many dark days were the result. About 1885 natural gas became very plentiful and cheap, largely supplanting soft coal as a fuel, and the air became comparatively free from smoke. The price of gas was increased about 1895, and the use of soft coal was again resorted to, with the result that the air was again filled with smoke. In the years 1905–1907 many days with dense smoke were recorded; but the panic of 1907–8 resulted in a diminished use of coal in manufactories, and there has been an improvement in domestic furnaces and methods of stoking, so that the volume of smoke has again been greatly diminished. However, the air in the vicinity of Pittsburgh is never free from smoke, except after a rain or snow storm, and with high westerly winds.

In Table 4 the average maximum and minimum temperatures and the range of temperature, in Pittsburgh, have been arranged in four groups: (1) 1875–1884, corresponding to a period of dense smoke, according to the above statement; (2) 1885–1894, to a period of comparatively light smoke; (3) 1895–June, 1904, to a period of dense smoke; and (4) July, 1904–Dec., 1911, to a period of decreasing smokiness.

TABLE 4.—*Average annual maximum and minimum temperature and range of temperature at Pittsburgh, Pa.*

Period.	1875–1884	1885–1894	1895–June, 1904	July, 1904–1911
	°F.	°F.	°F.	°F.
Maximum	62.7	61.9	61.9	61.0
Minimum	43.4	44.0	44.6	43.6
Range	19.3	17.9	17.3	17.5

The elevation of the thermometers above ground was about 88 feet during the first period, about 120 feet during the second and third periods, and 336 feet during most of the fourth period. The increase in elevation at the end of the first period appears to have decreased the diurnal range of temperature about 1.4° F., while the further increase in elevation at the end of the third period appears to have decreased both maximum and minimum temperatures by about 1° F. During the smoky third period the minimum temperatures averaged about 0.6° F. higher than during the comparatively clear second period.

While in each of these cases the temperature shifts are in the direction in which we would expect them to occur as the result of the local conditions above described, we can not state with certainty that they are entirely the result of changes in the elevation of the instruments, or of variations in the smokiness of the atmosphere. It may be that changes in the character of the instrument shelter, as from a window to a roof shelter, and in the character of surrounding buildings, may also have exerted an influence, the extent of which it is impossible to estimate.

In Table 5 are summarized comparisons between the minimum temperature and the range of temperature at the Weather Bureau office in St. Louis and the suburban station in Forest Park; at the Weather Bureau office in Columbus, Ohio, and the suburban station at the State University; and at the Weather Bureau offices in Pittsburgh, Pa., Philadelphia, Pa., Williamsport, Pa., and Harrisburg, Pa., and at stations surrounding these centers, but in some cases several miles distant, and at a considerably different elevation above sea level.

The comparisons for St. Louis include observations for 1 year, those for Columbus 29 years, and those for the four remaining stations the 10 years 1902–1911, inclusive.

TABLE 5.—*Excess of minimum temperatures, and deficiency of range of temperature in cities as compared with the surrounding country.*

Month.	St. Louis.		Columbus.		Pittsburgh.		Philadelphia.		Williamsport.		Harrisburg.	
	Min.	Range.	Min.	Range.	Min.	Range.	Min.	Range.	Min.	Range.	Min.	Range.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
January	2.5	1.6	2.1	2.0	3.0	3.0	3.6	2.7	3.0	2.8	2.6	3.7
February	2.9	2.8	1.2	1.3	2.6	2.5	3.8	3.2	2.6	2.3	2.6	4.3
March	1.6	0.5	2.7	2.3	3.7	3.8	4.0	4.2	2.8	2.9	4.2	4.7
April	4.4	3.7	3.2	3.6	3.8	5.6	4.7	4.3	3.0	2.9	3.6	5.9
May	5.5	4.8	3.2	3.3	5.2	6.9	3.9	4.1	3.2	3.3	4.2	6.9
June	3.7	2.3	2.8	2.9	4.5	5.8	3.7	3.0	2.8	3.2	3.3	5.9
July	5.5	4.0	3.2	3.4	4.9	6.2	4.5	4.4	3.2	4.2	4.3	6.4
August	4.8	4.2	3.4	4.1	5.0	6.6	4.4	4.4	2.2	3.8	3.7	6.1
September	9.0	9.0	3.5	4.3	4.4	7.6	4.7	4.2	2.8	3.4	3.5	5.3
October	5.8	5.9	3.8	4.5	4.4	5.9	5.6	5.7	2.7	2.8	3.8	5.6
November	2.2	2.2	2.9	3.2	4.5	4.6	5.1	4.5	2.4	3.0	3.7	5.0
December	1.5	1.5	1.9	2.0	3.0	3.1	5.0	3.2	2.7	2.7	3.1	4.3
Year	4.1	3.5	2.8	3.1	4.1	5.1	4.4	4.0	2.8	3.1	3.6	5.4

At the outlying stations, and also at Williamsport, the thermometers have been exposed in a shelter but a few feet above the ground. At Pittsburgh they are now 353 feet above the ground, at Philadelphia 123 feet, and at Harrisburg 94 feet; but the elevation at Pittsburgh has been changed during the period of comparison, as has already been shown.

From Table 5, it is seen that the minimum temperature at the six stations under consideration averages about 3.6° F. higher, and the range of temperature 4° less than the corresponding data for surrounding stations. The maximum temperature must therefore average about 0.4° lower. The differences have a maximum in the warm months of the year.

The maximum temperatures in the city are generally low during the warm months by approximately the amount that may be attributed to the greater elevation of the thermometers above the ground, or by about 0.5° F. per 100 feet. Only a part of the minimum temperature excess can be attributed to this cause, the rest being undoubtedly due to some city influence.

Bolton (**30**) has computed that the total heat emitted from all sources in the city of New York, but principally from the combustion of fuel in average winter temperature of 40° F., would add 2° F. to the temperature over an area of 326 square miles to a height of 1 mile. This could only be true when there was no movement of the atmosphere, a condition that only occasionally prevails; and the effects of the heating would be more marked in winter than in summer. Evidently some other influence also has a part in modifying the minimum temperatures of cities.

Table 6 shows that in cities the minimum temperature excess is more pronounced on days when dense smoke prevails. We are therefore justified in attributing a part of the excess in the monthly mean minimum temperature of cities to the general smokiness of their atmospheres.

TABLE 6.—*Departures of the maximum and minimum temperature and the range of temperature in cities, when smoke or fog was dense, from the corresponding averages at surrounding stations.*

Station.	Maximum.	Minimum.	Range.
	° F.	° F.	° F.
Pittsburgh	−0.9	+6.5	−7.4
Philadelphia	−0.4	+6.9	−7.3

Table 6 also shows that the maximum temperatures are not affected to the same extent as the minimum temperatures. This is because the smoke is densest during the morning hours, the convection of midday helping to carry it away. At the same time the more thorough mixture of city and country air tends to equalize temperatures over the two regions, and it may also be that the absorption of heat by the smoke particles tends to increase the maximum temperatures.

Williamsport, Pa., is a small city in which the effects of city heating must be slight; and since the thermometers have had exposures similar to those at surrounding stations, namely, in a shelter a few feet above the ground, the only known reason why the minimum temperature should show the excess revealed by Table 5 is the influence of the smoke cloud, which is quite dense at times owing to the extensive use of bituminous coal for manufacturing purposes.

Between December, 1912, and May, 1913, inclusive, temperature readings were obtained from thermometers exposed a few feet above the sod in a park in Allegheny, Pa., just across the river from the Weather Bureau office in Pittsburgh, and from thermometers similarly exposed at Sewickley, Pa. The results, which are summarized in Table 7 show rather small differences between the readings at Allegheny and the Weather Bureau office in Pittsburgh, but differences between the readings at Allegheny and Sewickley of about the magnitude that would be expected from the comparisons summarized in Table 5.

Other conditions being equal, the diurnal range of temperature should be proportional to the amount of heat received during the day; but, as already stated, it seems probable that in the cases under consideration the diminished diurnal range of temperature is due principally to retardation of nocturnal cooling by the smoke cloud over the cities.

TABLE 7.—*Differences between temperatures in Pittsburgh and its suburbs.*

Stations.	Maximum.	Minimum.	Range.
	° F.	° F.	° F
Allegheny—Weather Bureau, Pittsburgh	+0.8	−0.3	+1.1
Allegheny—Sewickley	−0.1	+3.3	−3.4
Sewickley—Weather Bureau, Pittsburgh	+0.9	−3.6	+4.5

I am indebted to Mr. George S. Bliss, section director, United States Weather Bureau, in charge of the Pennsylvania section, for the data for Philadelphia, Williamsport, and Harrisburg, and for information relative to conditions prevailing at these stations.

SUMMARY.

1. City fogs are more persistent than country fogs, principally because of their increased density on account of the smoke that accumulates in them.
2. In consequence of the above there are fewer hours of sunshine in cities than in the country.
3. In the clear part of the day in winter in London the average limit of visibility does not exceed one-half mile. In Pittsburgh it averages about 1½ miles. This latter is less than one-tenth the average limit of visibility in the open country about Pittsburgh.
4. The chemical action of light in smoky cities has been found to be 40 per cent less than in the open country, and over 20 per cent less on smoky days than on comparatively clear days.
5. Minimum temperatures are markedly higher in cities than in the country, partly on account of city heating, but principally because the smoke acts as a blanket to prevent the escape of heat at night.

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